

ELECTRONIC FUNDAMENTALS

THEORY LESSON 26

DECIBELS, MICROPHONES, AND LOUDSPEAKERS

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Theory Lesson 26

INTRODUCTION

You are going to study the means by which sound enters the transmitter — the microphone — and the means by which it leaves a receiver — the loudspeaker. In order to understand this process and interpret certain ratings that manufacturers put on their components, you need to understand a system of measurement originally based upon some fascinating facts about the way in we hear sound. So, before we consider microphones and loudspeakers, let's examine the measuring unit known as the decibel.

26-1. THE DECIBEL

Experiments dealing with the way in which we hear have proved that the human ear does not respond to sounds linearly. That is, if a certain amount of mechanical energy produces a certain audible sound, twice as much energy will not produce an audible sound that is twice as loud. Approximately, 10 times as much mechanical energy is required to make an audible sound that is twice as loud as the first one. And 100 times as much mechanical energy is needed to double it again (to four times the original loudness).

Let's express the relationship between the mechanical energy required to produce audible sound and the audible sound it produces in powers of ten. Instead of saying that it takes 10 times as much energy to produce 2 times a given audible sound and 100 times as much power to produce 4 times a given audible sound, let's say that it takes 10^1 times as much energy to produce 2 times as much audible sound and 10^2 energy to produce 4 times as much audible sound. We could extend this indefinitely; 10^3 energy produces 8 times as much audible sound, 10^4

energy produces 16 times as much audible sound, etc. With each doubling of loudness, the power of ten increases by 1.

Now let's convert powers of ten into a new system that will make it very easy to measure decibels. First let's set down a few numbers and the powers of ten to which they are equal.

$$100 = 10^2$$

$$1,000 = 10^3$$

$$10,000 = 10^4$$

Now let's answer some questions that may seem very simple. To get 100, what exponent must you put next to the 10. The answer of course is 2. To get 1,000, what exponent do you need. The answer is 3. To get 10,000, the exponent is 4.

In other words:

$$\text{The exponent required to get 100} = 2$$

$$\text{The exponent required to get 1,000} = 3$$

$$\text{The exponent required to get 10,000} = 4$$

It would be better if our statements were not so wordy. Let's substitute the word logarithm, or, better still, its abbreviation log, for all the words in the statements above. Now we have:

$$\log 100 = 2$$

$$\log 1,000 = 3$$

$$\log 10,000 = 4$$

At last we have some simple numbers to work with. Now let's talk about mechanical energy and audible sound again and see how much easier this system makes our measurements.

We can use our knowledge of logs to help us relate a change in audible sound to the change in mechanical energy required to produce it.

A formula we might use is:

$$\text{bels} = \log \frac{P_2}{P_1}$$

But the bel, a unit named after Alexander Graham Bell, the inventor of the telephone, is not used as a practical measurement. Instead, one tenth of a bel or a decibel, abbreviated db, is used, so the formula usually used is:

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

Now let's go back to our original example. We said that in order to get four times as much audible sound, we had to have 100 times as much mechanical energy or power. What's the power ratio equivalent to in decibels?

The higher power is P_2 , and it is 100 times as much as P_1 . Therefore:

$$\frac{P_2}{P_1} = \frac{100}{1}$$

Therefore:

$$\begin{aligned} \text{db} &= 10 \log \frac{100}{1} \\ &= 10 \log 100 \\ &= 10 (2) \\ &= 20 \end{aligned}$$

The new loudness is 4 times as loud as the original loudness, and the power (energy) increase is 20 db.

Let's use the same formula again. We want to know by how many db the mechanical power will increase if we now *start* at 100 times as much as we had to begin with and raise it 10,000 times as much as we had to begin with (that is, if we quadrupled the loudness again). We can use the same formula:

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

This time P_2 becomes 10,000 and P_1 becomes 100. So:

$$\begin{aligned} \text{db} &= 10 \log \frac{10,000}{100} \\ &= 10 \log 100 \\ &= 10 (2) \\ &= 20 \end{aligned}$$

This new loudness is 4 times the previous loudness and again the power increase is 20 db.

Notice that what we have been doing is comparing two *relative* powers, even though we do not know their absolute values. All we know is the proportion of one power to another.

We know that if we use 100 times as much mechanical power, no matter how much power we start with, the power that results will be 20 db greater, and the sound 4 times louder.

Up to this point, we have been concerned with mechanical power and sound. We have seen that, if we have a change to P_2 from P_1 , the result can be given in decibels. What is expressed in decibels need not concern sound, and the power that changes can be electrical power instead of mechanical power.

For example, the db is often used in discussing the gain of amplifiers. Let's suppose

that an amplifier has such a gain that the power to its input is increased by 1,000 times at its output. In other words, P_2 is 1,000 and P_1 is 1. Let's use our formula:

$$\begin{aligned} \text{db} &= 10 \log \frac{1,000}{1} \\ &= 10 \log 1,000 \\ &= 10 (3) \\ &= 30 \end{aligned}$$

So, instead of saying that the gain of the amplifier is 1,000, we can say that the gain is 30 db.

Reference Level. We may know what the input power of the amplifier is. For instance, let's suppose that 1 milliwatt is applied to the input. Then, the output is 30 db above 1 milliwatt. You can see we are comparing the changes to 1 milliwatt. The 30 db is with respect to the input. Therefore, we can call the input the *reference level*. Reference level means a quantity to which we can compare other quantities. It need not be an amplifier input.

We can convert 30 db more than 1 milliwatt into an output expressed in watts by starting with the formula you have already learned.

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

Substituting, we get:

$$30 = 10 \log \frac{P_2}{1}$$

The unknown term is P_2 . It will be easier if we convert from decibels to bels by dividing both sides of the equation by 10. Therefore:

$$3 = \log \frac{P_2}{1}$$

Stated in words, this means that 3 is the log of a number that you would get if you divided P_2 by 1. More simply stated, 3 is

the log of P_2 . As you know from your study of the principle of logs, if we call a number a log we can also call it an exponent for a power of ten.

Therefore, instead of saying $3 = \log P_2$, we can say $10^3 = P_2$. Now we know that P_2 is 1,000 times greater than P_1 . If P_1 is 1 milliwatt, P_2 is 1 watt.

You will notice that 1 milliwatt is often used as the standard reference level. However, because other reference levels, such as 6 milliwatts and 12 milliwatts have been used in the past, the 1 milliwatt reference level is always mentioned when it is used. The symbol for this 1 milliwatt reference level is m , and it is always used when the discussion of db involves this reference level. For instance, in the discussion above, we spoke of 30 db over a reference level, of 1 milliwatt. This can be expressed as 30 dbm. This means that the power we are speaking of is 30 db more than 1 milliwatt reference level.

According to the same principle, 30 dbm equals 1 watt, 40 dbm equals 10 watts, 50 dbm equals 100 watts, etc.

Decibel Meter. A voltmeter can be calibrated to read directly in decibels and used to measure power level in decibels. The voltmeter is used to measure power. Thus, a particular voltage reading is made to stand for a particular power level, and this power is read in decibels. Here is how it's done. The voltmeter in Fig. 26-1 measures 25 volts across a 600 ohm resistor. The

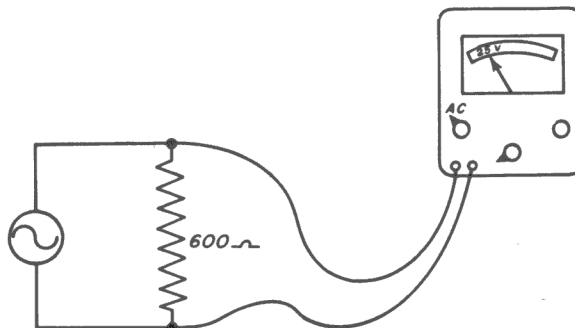


Fig. 26-1

voltage of 25 volts across 600 ohms causes approximately 1 watt of power to be dissipated in the resistor.

$$\begin{aligned}
 P &= \frac{E^2}{R} \\
 &= \frac{(25)^2}{600} \\
 &= \frac{625}{600} \\
 &= 1 \text{ watt} \\
 &\quad (\text{approx})
 \end{aligned}$$

A power level of 1 watt, stated in decibels, is 30 dbm. If you do not understand why this is so, reread the discussion of reference levels. Consequently, when 25 volts is measured across 600 ohms resistance, the power level at the point of measurement is 30 dbm. Other amounts of voltage are placed across the resistor in order to calibrate the meter for other values of dbm. If a 60-ohm resistor were substituted for a 600-ohm resistor, 25 volts would no longer result in 1 watt of power. Instead:

$$\begin{aligned}
 P &= \frac{E^2}{R} \\
 &= \frac{(25)^2}{60} \\
 &= \frac{625}{60} \\
 &= 10 \text{ watts} \\
 &\quad (\text{approx})
 \end{aligned}$$

Ten watts is 10,000 times more than the 1 milliwatt reference level. Ten watts, stated in decibels is 40 dbm.

A voltmeter can be calibrated to read decibels across only one value of resistance. For all other resistances, the meter reading must be increased or decreased by a correction factor. It is important to know the resistance across which a stated db power level exists.

Voltage Reference Levels. We have discussed how a voltmeter might be made to read power, and, therefore, dbm. It may have occurred to you as you read that if power dbm measurements can be made with a voltmeter, it might be possible to express voltage ratios in decibels.

It is, in fact, possible to express voltage ratios in decibels provided that resistance is taken into account. If you know the resistance across which an unknown voltage was measured to produce a particular number of dbm, you can calculate the amount of power and the amount of voltage that passed across the resistance to produce that power.

Let's take an example and see how the conversion we are talking about can be made. Suppose we have a value of 30 dbm and we know that the measurement of this value was made on a resistance of 600 ohms. The *m* in 30 dbm tells us that the power reference level is 1 milliwatt, and that therefore 30 dbm stands for a power of 1 watt. Furthermore, the fact that the decibel measurement was made across a resistance of 600 ohms makes it possible to calculate that roughly 25 volts produced the decibel reading.

Now let's consider all the things we know when we read 30 dbm on the meter we have described. We know that there is a power of 1 watt. We also know that this power was produced by placing a voltage of 25 volts across a resistance of 600 ohms. If we knew only the 30 dbm and the resistance, we could calculate the power and the voltage. Therefore, all we need to speak of is the 30 dbm across 600 ohms.

Since 600 ohms is usually the value of resistance for which db meters are calibrated, 600 ohms is a kind of reference level just like 1 milliwatt. The term 30 dbm across 600 ohms is abbreviated as 30 *vu* (pronounced vee-you). The meter that we are talking about (a voltmeter that has been calibrated to read in decibels across 600 ohms) is called a *vu meter*. Vu meters are used only to mea-

sure the electrical waveforms resulting from an actual sound as for monitoring purposes in radio and television broadcasting stations, for tape recording, and for other sound monitoring applications.

Voltage Ratios. We have seen that if we know a reading in vu, we can calculate the voltage involved in the dbm measurement. You might suspect, from this, that there is a way of expressing change in voltage in decibels. This is so, but the formula is different. Instead of using the power formula, which is:

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

we use the voltage formula, which is:

$$\text{db} = 20 \log \frac{E_2}{E_1}$$

Let's compare a power measurement in db with a voltage measurement. If you see the term 30 vu, you can translate it to mean 30 dbm across 600 ohms. This means that P_2 , which is across the 600 ohms, is 1 watt. This makes it possible to find the voltage, which is 25 volts. The 25 volts is E_2 of the formula. E_1 is the reference power (one milliwatt across 600 ohms) converted to volts. We can find the value of E_1 as follows:

$$P = \frac{E^2}{R}$$

$$1 \text{ milliwatt} = 0.001 \text{ watt} = \frac{E^2}{600}$$

$$E^2 = 0.6$$

$$E = \sqrt{0.6} = 0.77 \text{ (approx)}$$

E_1 is 0.77 volts. Since we know the values of E_1 and E_2 , we can use the voltage formula as follows:

$$\text{db} = 20 \log \frac{E_2}{E_1}$$

$$\begin{aligned} \text{db} &= 20 \log \frac{25}{0.77} \\ &= 20 \log 32 \end{aligned}$$

Since:

$$32 = 10^{1.5}, \log 32 = 1.5$$

$$\text{db} = 20 (1.5)$$

$$= 30 \text{ (approximately)}$$

The decibel ratio in volts is 30 db.

Thus, a change in voltage can be expressed in decibels. We started with 30 db above a reference level of 1 milliwatt across 600 ohms. We ended with voltage expressed as 30 db above a reference level of 0.77 volt across 600 ohms.

By converting power to voltage, we found that the decibel ratio could be stated in either power or volts.

Notice that 0.77 volt is a reference level for the voltage ratio, just as 1 milliwatt is the reference level for the power ratio.

Interpreting Decibel Measurements. Let's take an over-all look at what we've discussed so far. You have learned that you can express gain or loss of power by means of the formula:

$$\text{db} = 10 \log \frac{P_2}{P_1}$$

So long as you are not concerned with actual numerical values, all you need is this ratio.

When you are dealing in actual numerical values, you need a reference value. This reference value is an actual numerical value. The reference value usually used is 1 milliwatt. This reference value is indicated in the term dbm. The m stands for the reference value. When you read 30 dbm, you know that you are reading 30 db over a reference level of 1 milliwatt.

When you identify power by db of voltage across a given resistance, you have some additional useful information. A resistance often used as a reference resistance is 600 ohms. But, instead of speaking of 30 dbm across 600 ohms, we might say 30 vu.

When we say 30 vu, we have a statement based upon three important things:

1. The ratio $\frac{P_2}{P_1}$
2. The reference level (1 milliwatt)
3. The resistance factor (600 ohms)

If any one of these three were changed, our expression would not mean the same thing.

Note: One of the most important things to remember when you read decibel notations is that the number of decibels gives you only a ratio. What you read will have meaning for you only if you know the reference level and resistance factor where these are necessary.

Voltage Gain or Loss – The Voltage Decibel. Just as we spoke of power gain or loss without a reference level, so we can speak of voltage gain or loss. The important thing to remember is that you cannot convert voltage gain or loss to power gain or loss without knowing the resistance factor.

Let's return to our discussion of voltage and db. We have shown how the statement 30 vu can be converted to a db reading based on voltage. We have pointed out that the equivalent of the 1 milliwatt reference level in 30 vu is the 0.77 volt reference level when we are dealing with voltage.

The resistance level is very important in db measurements of voltage. Since db is a measurement of power, the relationship between the power and the voltage depends upon the resistance level. Without information about the resistance level, you cannot convert voltage levels to power levels.

Voltage ratios are used without the resistance factor because they provide a practical way of stating *voltage* gain or loss (also voltage level) in logarithm units. Although the decibel is the unit of measure used, no information about power is intended.

Since decibels are a unit used in measuring power, the units used to measure voltage gain or loss do not represent true decibels.

Here's an example of the use of decibels-of-voltage statements where no statement of power is intended. Consider the voltage amplifier. If a voltage amplifier has a gain of 100 times, then one volt (E_1) at the input causes 100 volts (E_2) to appear at the output.

Expressed in so-called voltage decibels the ratio is 40 db

$$\begin{aligned} \text{db} &= 20 \log \frac{E_2}{E_1} \\ &= 20 \log 100 \\ &= 20 \times 2 \\ &= 40 \end{aligned}$$

The voltage gain of this amplifier remains at 100 times, regardless of the resistance across which the 1 volt input is developed. Yet the power consumed in the input changes when the resistance is changed (as when the amplifier is connected to two alternate voltage sources, each with a different internal resistance). One volt across 1,000 ohms develops one milliwatt. One volt across 1,000,000 ohms develops 0.001 milliwatt.

$$P = \frac{E^2}{R}$$

Because a single voltage input can co-exist with different input powers there can be different power gains where the voltage gains are identical. If the output power is 500 milliwatts, the power gain with a 1,000-ohm (1 milliwatt) input would be 500, and that with a 1,000,000 ohm (0.001 milliwatt) input would be 500,000. The voltage gain in each case is 100.

A statement of voltage gain in true decibels would reflect the difference in power gains. But this would be misleading, be-

cause voltage gain alone is what we are concerned with in this case. Therefore, the gain of voltage amplifiers is frequently stated as decibel ratio of voltages without taking resistance into account.

Although it would be simpler if both the power and the voltage unit of measurement were not called a decibel, there is no means provided to tell them apart unless the resistance factor is included in statements of true decibels and is given separately in ohms. This is done when a statement of voltage *level* is made in true decibels but not when a statement of true decibels of voltage *gain* is made. The resistance factor, necessary with true decibels is worked into the decibel voltage gain ratio:

$$20 \log \frac{E_2}{E_1}$$

by the following factor:

$$10 \log \frac{R_1}{R_2}$$

where

R_1 is the resistance across which
 E_1 develops

R_2 is the resistance across which
 E_2 develops

Here is the formula for so-called decibels of voltage gain: for clarity these decibels are written *dbvg*; *vg* means voltage gain:

$$\text{dbvg} = 20 \log \frac{E_2}{E_1}$$

The formula for *true* decibels of voltage gain, which are numerically the same as power decibels, is:

$$\text{db} = 20 \log \frac{E_2}{E_1} + 10 \log \frac{R_1}{R_2}$$

To illustrate the difference between the two formulas, let us continue with our voltage amplifier calculations. From the formula

$$20 \log \frac{E_2}{E_1}$$

we have found the gain in so-called decibels of voltage is 40 db (now we write 40 dbvg). Assuming that the output resistance (R_2) of the amplifier is 1,000 ohms, we find the voltage gain in true decibels with a 1,000,000 ohm input as follows:

$$\begin{aligned} \text{db} &= 20 \log \frac{E_2}{E_1} + 10 \log \frac{R_1}{R_2} \\ &= 40 + 10 \log \frac{1,000,000}{1,000} \\ &= 40 + 10 \log 1,000 \\ &= 40 + 10 (3) \\ &= 40 + 30 \\ &= 70 \end{aligned}$$

The voltage gain in true decibels with a 1,000 ohm input is:

$$\begin{aligned} \text{db} &= 20 \log \frac{E_2}{E_1} + 10 \log \frac{R_1}{R_2} \\ &= 40 + 10 \log \frac{1,000}{1,000} \\ &= 40 + 10 \log 1 \end{aligned}$$

The logarithm of number 1 is 0 so:

$$\begin{aligned} \text{db} &= 40 + 10 (0) \\ &= 40 + 0 \\ &= 40 \end{aligned}$$

To list the result of our calculations:

1. The gain of the amplifier in voltage decibels is 40 dbvg.
2. The voltage gain in true decibels is as follows:

With 1,000,000 ohms input and 1,000 ohms output, the gain is 70 db.

With 1,000 ohms input, 1,000 ohms output, the gain is 40 db.

As you see, the voltage gain in true decibels (40 db) equals the voltage gain in voltage decibels (40 dbvg) when the resistances R_1 and R_2 are equal.

At the beginning of this lesson, you learned how the logarithms of multiples of 10 were found. But in the last calculations we made, we used the log of 0. Although the log of 0 or any other number can be found, and even though there are tables of logarithms in which you can find the log of any number, we do not need to consider these tables in our study of decibels.

Tables of decibels enable you to make decibel calculations without using log tables. But before we take up the calculations, let's consider another way in which power decibels and voltage decibels are different.

Advantage of Using Voltage Decibels for Gain Measurements. The decibel measures electric power so that the units of electric power correspond with the way the human ear measures sound power.

But decibels are also used to measure voltage. Voltage decibels do not offer an electrical measurement that corresponds exactly to the way our ears measure sound. Yet we take the trouble to convert the gain

of a voltage amplifier to voltage decibels in order to benefit from the advantage of using decibels (both voltage decibels and true decibels).

To understand this new advantage, let's examine what happens when you connect two amplifiers in series if both amplifiers have a gain of 10. If 1 volt is applied to the input of the first amplifier, the output of that amplifier is 10 volts. When this 10 volts is applied to the input of the second amplifier, the output of the second amplifier is 100. So, 1 volt applied to two amplifiers with a gain of 10 each connected in series results in 100 volts at the output of the second amplifier.

You can see that you can find the gain of amplifiers connected in series by multiplying the gain of one amplifier by the gain of the other amplifier. If three amplifiers were connected in series, you would multiply the gain of the first by the gain of the second and multiply the total by the gain of the third.

If the two amplifiers, each with a gain of 10, were connected together by cable with a loss of 10 (this means that the output is one-tenth as great as the input), we would have the following situation. One volt at the input of the first amplifier would result in 10 volts at the output of the first amplifier. This 10 volts applied to the input side of the cable would result in one volt at the output end of the cable. This 1 volt, applied to the input of the second amplifier, would result in 10 volts at the output of the second amplifier.

It is possible to express what happens in a formula by multiplying the gains and dividing by the losses. For example, in the case we have just discussed:

$$\frac{10 \times 10}{10} = 10$$

Servicemen speak of gain that results in amplification as *gain up*, and losses that result in a reduction of amplification as *loss down*. In the example we just discussed, each amplifier had a gain of 10 up, and the cable had a loss of 10 down.

It is easier to add and subtract than to multiply and divide. By using decibels, you can find the result of gains and losses in a circuit by addition and subtraction rather than by multiplication and division. This is the advantage of using decibels for voltage gain measurements. For instance, we need not express the gain and loss as:

$$\frac{10 \times 10}{10} = 10$$

Instead, we can write:

$$20 \text{ db} + 20 \text{ db} - 20 \text{ db} = + 20 \text{ db}$$

The total has a + sign to show that it is gain up and not loss down.

Either true decibels or voltage decibels can be added and subtracted in this way. *However, it is not proper to combine true decibels with voltage decibels by this means.*

Level and Voltage Decibels. Like the true decibel, the voltage decibel is used to measure level as well as gain. The standard reference level for the power decibels is 1 milliwatt. The most commonly used reference level for voltage decibels (true or otherwise) is 1 volt. The abbreviation for decibels to the 1 volt reference is dbv. Thus, a level of 1,000 volts is written *60 db above 1 volt or 60 dbv*. This is a measure of absolute level. That is, it always means 1.00' volts.

There is another kind of level measurement, made with either kind of decibel, called a relative level. This measurement is used because the gains and losses of amplifiers are not the same at all frequencies. For example, we might say of an audio amplifier that it is *down 3 db below one kc at 60 cycles per second*. This means that the amplifier's output at sixty cycles per second is lower than whatever it happens to be at

1,000 cycles per second (one kc) by 3 db. The statement does not tell you what the level at one kc is. The 60 cps level does not represent a particular voltage or power as do statements of absolute level.

Using Decibel Tables. Tables A and B, reproduced by permission of the *Radiotron Designer's Handbook*, edited by F. Langford-Smith are useful in decibel calculations. Table A can be used to find a voltage or power ratio when you know the number of decibels.

The center column gives the number of db. The columns headed *Voltage Ratio* tell you the corresponding number of volts at the output if the reference level is one volt. In other words, the voltage ratio is:

$$\frac{E_2}{E_1}$$

In this table E_1 is 1 in all cases. Therefore, only the values of E_2 are listed. Let's try an example. You know that an amplifier has an output of 14 dbv. What is the value of E_2 ? Opposite 14 in the db column you see the number 5.012, which is the value of E_2 . If, in addition, the amplifier gain is 14 dbvg, for every 1 volt at the input, there will be 5.012 volts at the output. Thus if you have 3 volts at the input, the number of volts at the output is 3×5.012 , or 15.036 volts.

The two columns *right* of center are used if the db figure is positive, indicating a voltage (or power) gain. The two columns *left* of center are used if the db figure is negative, indicating a voltage (or power) loss.

The same number of db in the center column refers to a different ratio when we are considering power. The power ratios are listed in the columns headed *Power Ratio*.

If we look for the power ratio for which 14 db stands, we find that it is 25.12. The subhead for the *Power Ratio* column explains that this number stands for milliwatts when the reference level is 1.

Thus, we know that P_1 is always 1 milliwatt, and that, if the gain of the amplifier is

TABLE A - DECIBELS EXPRESSED AS POWER AND VOLTAGE RATIOS
 LOSS GAIN

Voltage or Current Ratio I.V. REF LEVEL	Power Ratio (= mW to Reference Level 1 mW)	db	Voltage or Current Ratio I.V. REF LEVEL	Power Ratio (= mW to Reference Level 1 mW)
1.000 0	1.000 0	-0+	1.000	1.000
.988 6	.977 2	0.1	1.012	1.023
.977 2	.955 0	0.2	1.023	1.047
.966 1	.933 3	0.3	1.035	1.072
.955 0	.912 0	0.4	1.047	1.096
.944 1	.891 3	0.5	1.059	1.122
.933 3	.871 0	0.6	1.072	1.148
.912 0	.831 8	0.8	1.096	1.202
.891 3	.794 3	1.0	1.122	1.259
.841 4	.707 9	1.5	1.189	1.413
.794 3	.631 0	2.0	1.259	1.585
.749 9	.562 3	2.5	1.334	1.778
.707 9	.501 2	3.0	1.413	1.995
.631 0	.398 1	4	1.585	2.512
.562 3	.316 2	5	1.778	3.162
.501 2	.251 2	6	1.995	3.981
.446 7	.199 5	7	2.239	5.012
.398 1	.158 5	8	2.512	6.310
.354 8	.125 9	9	2.818	7.943
.316 2	.100 0	10	3.162	10.000
.281 8	.079 43	11	3.548	12.59
.251 2	.063 10	12	3.981	15.85
.223 9	.050 12	13	4.467	19.95
.199 5	.039 81	14	5.012	25.12
.177 8	.031 62	15	5.623	31.62
.158 5	.025 12	16	6.310	39.81
.141 3	.019 95	17	7.079	50.12
.125 9	.015 85	18	7.943	63.10
.112 2	.012 59	19	8.913	79.43
.100 0	.010 00	20	10.000	100.00
.089 13	.007 943	21	11.22	125.9
.079 43	.006 310	22	12.59	158.5
.070 79	.005 012	23	14.13	199.5
.063 10	.003 981	24	15.85	251.2
.056 23	.003 162	25	17.78	316.2
.050 12	.002 512	26	19.95	398.1
.044 67	.001 995	27	22.39	501.2
.039 81	.001 585	28	25.12	631.0
.035 48	.001 259	29	28.18	794.3
.031 62	.001 000	30	31.62	1 000
.028 18	7.943×10^{-4}	31	35.48	1 259
.025 12	6.310×10^{-4}	32	39.81	1 585
.022 39	5.012×10^{-4}	33	44.67	1 995
.019 95	3.981×10^{-4}	34	50.12	2 512
.017 78	3.162×10^{-4}	35	56.23	3 162
.015 85	2.512×10^{-4}	36	63.10	3 981
.014 13	1.995×10^{-4}	37	70.79	5 012
.012 59	1.585×10^{-4}	38	79.43	6 310
.011 22	1.259×10^{-4}	39	89.13	7 943
.010 000	1.000×10^{-4}	40	100.0	10 000
.008 913	7.943×10^{-5}	41	112.2	12 590
.007 943	6.310×10^{-5}	42	125.9	15 850
.007 079	5.012×10^{-5}	43	141.3	19 950
.006 310	3.981×10^{-5}	44	158.5	25 120
.005 623	3.162×10^{-5}	45	177.8	31 620
.005 012	2.512×10^{-5}	46	199.5	39 810
.004 467	1.995×10^{-5}	47	223.9	50 120
.003 981	1.585×10^{-5}	48	251.2	63 100
.003 548	1.259×10^{-5}	49	281.8	79 430
.003 162	1.000×10^{-5}	50	316.2	100 000
.002 818	7.943×10^{-6}	51	354.8	125 900
.002 512	6.310×10^{-6}	52	398.1	158 500
.002 239	5.012×10^{-6}	53	446.7	199 500
.001 995	3.981×10^{-6}	54	501.2	251 200
.001 778	3.162×10^{-6}	55	562.3	316 200
.001 585	2.512×10^{-6}	56	631.0	398 100

TABLE A-DECIBELS EXPRESSED AS POWER AND VOLTAGE RATIOS (CONT.)

Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)	db	Voltage or Current Ratio	Power Ratio (= mW to Reference Level 1 mW)
.001 413	1.995×10^{-6}	57	707.9	501 200
.001 259	1.585×10^{-6}	58	794.3	631 000
.001 122	1.259×10^{-6}	59	891.3	794 300
.001 000	1.000×10^{-6}	60	1 000	1 000 000
8.91×10^{-4}	7.943×10^{-7}	61	1 122	1.259×10^6
7.94×10^{-4}	6.310×10^{-7}	62	1 259	1.585×10^6
7.08×10^{-4}	5.012×10^{-7}	63	1 413	1.995×10^6
6.31×10^{-4}	3.981×10^{-7}	64	1 585	2.512×10^6
5.62×10^{-4}	3.162×10^{-7}	65	1 778	3.162×10^6
5.01×10^{-4}	2.512×10^{-7}	66	1 995	3.981×10^6
4.47×10^{-4}	1.995×10^{-7}	67	2 239	5.012×10^6
3.98×10^{-4}	1.585×10^{-7}	68	2 512	6.310×10^6
3.55×10^{-4}	1.259×10^{-7}	69	2 818	7.943×10^6
3.16×10^{-4}	1.000×10^{-7}	70	3 162	1.000×10^7
2.82×10^{-4}	7.943×10^{-8}	71	3 548	1.259×10^7
2.51×10^{-4}	6.310×10^{-8}	72	3 981	1.585×10^7
2.24×10^{-4}	5.012×10^{-8}	73	4 467	1.995×10^7
1.99×10^{-4}	3.981×10^{-8}	74	5 012	2.512×10^7
1.78×10^{-4}	3.162×10^{-8}	75	5 623	3.162×10^7
1.58×10^{-4}	2.512×10^{-8}	76	6 310	3.981×10^7
1.41×10^{-4}	1.995×10^{-8}	77	7 079	5.012×10^7
1.26×10^{-4}	1.585×10^{-8}	78	7 943	6.310×10^7
1.12×10^{-4}	1.259×10^{-8}	79	8 913	7.943×10^7
1.00×10^{-4}	1.000×10^{-8}	80	10 000	1.000×10^8
8.91×10^{-5}	7.943×10^{-9}	81	11 220	1.259×10^8
7.94×10^{-5}	6.310×10^{-9}	82	12 590	1.585×10^8
7.08×10^{-5}	5.012×10^{-9}	83	14 130	1.995×10^8
6.31×10^{-5}	3.981×10^{-9}	84	15 850	2.512×10^8
5.62×10^{-5}	3.162×10^{-9}	85	17 780	3.162×10^8
5.01×10^{-5}	2.512×10^{-9}	86	19 950	3.981×10^8
4.47×10^{-5}	1.995×10^{-9}	87	22 390	5.012×10^8
3.98×10^{-5}	1.585×10^{-9}	88	25 120	6.310×10^8
3.55×10^{-5}	1.259×10^{-9}	89	28 180	7.943×10^8
3.16×10^{-5}	1.000×10^{-9}	90	31 620	1.000×10^9
2.82×10^{-5}	7.943×10^{-10}	91	35 480	1.259×10^9
2.51×10^{-5}	6.310×10^{-10}	92	39 810	1.585×10^9
2.24×10^{-5}	5.012×10^{-10}	93	44 670	1.995×10^9
1.99×10^{-5}	3.981×10^{-10}	94	50 120	2.512×10^9
1.78×10^{-5}	3.162×10^{-10}	95	56 230	3.162×10^9
1.58×10^{-5}	2.512×10^{-10}	96	63 100	3.981×10^9
1.41×10^{-5}	1.995×10^{-10}	97	70 790	5.012×10^9
1.26×10^{-5}	1.585×10^{-10}	98	79 430	6.310×10^9
1.12×10^{-5}	1.259×10^{-10}	99	89 130	7.943×10^9
1.00×10^{-5}	1.000×10^{-10}	100	100 000	1.000×10^{10}

TABLE B-POWER AND VOLTAGE OR CURRENT RATIOS EXPRESSED IN DECIBELS

Ratio	db (Power Ratio)	db (Voltage* Ratio)	Ratio	db (Power Ratio)	db (Voltage* Ratio)
1.0	0	0	2.7	4.314	8.627
1.1	0.414	0.828	2.8	4.472	8.943
1.2	0.792	1.584	2.9	4.624	9.248
1.3	1.139	2.279	3.0	4.771	9.542
1.4	1.461	2.923	3.1	4.914	9.827
1.5	1.761	3.522	3.2	5.051	10.103
1.6	2.041	4.082	3.3	5.185	10.370
1.7	2.304	4.609	3.4	5.315	10.630
1.8	2.553	5.105	3.5	5.441	10.881
1.9	2.788	5.575	3.6	5.563	11.126
2.0	3.010	6.021	3.7	5.682	11.364
2.1	3.222	6.444	3.8	5.798	11.596
2.2	3.424	6.848	3.9	5.911	11.821
2.3	3.617	7.235	4.0	6.021	12.041
2.4	3.802	7.604	4.1	6.128	12.256
2.5	3.979	7.959	4.2	6.232	12.465
2.6	4.150	8.299	4.3	6.335	12.669

TABLE B—POWER AND VOLTAGE OR CURRENT RATIOS EXPRESSED IN DECIBELS

Ratio	db (Power Ratio)	db (Voltage * Ratio)	Ratio	db (Power Ratio)	db (Voltage * Ratio)
4.4	6.435	12.869	7.4	8.692	17.385
4.5	6.532	13.064	7.5	8.751	17.501
4.6	6.628	13.255	7.6	8.808	17.616
4.7	6.721	13.442	7.7	8.865	17.730
4.8	6.812	13.625	7.8	8.921	17.842
4.9	6.902	13.804	7.9	8.976	17.953
5.0	6.990	13.979	8.0	9.031	18.062
5.1	7.076	14.151	8.1	9.085	18.170
5.2	7.160	14.320	8.2	9.138	18.276
5.3	7.243	14.486	8.3	9.191	18.382
5.4	7.324	14.648	8.4	9.243	18.486
5.5	7.404	14.807	8.5	9.294	18.588
5.6	7.482	14.964	8.6	9.345	18.690
5.7	7.559	15.117	8.7	9.395	18.790
5.8	7.634	15.269	8.8	9.445	18.890
5.9	7.709	15.417	8.9	9.494	18.988
6.0	7.782	15.563	9.0	9.542	19.085
6.1	7.853	15.707	9.1	9.590	19.181
6.2	7.924	15.848	9.2	9.638	19.276
6.3	7.993	15.987	9.3	9.685	19.370
6.4	8.062	16.124	9.4	9.731	19.463
6.5	8.129	16.258	9.5	9.777	19.554
6.6	8.195	16.391	9.6	9.823	19.645
6.7	8.261	16.521	9.7	9.868	19.735
6.8	8.325	16.650	9.8	9.912	19.825
6.9	8.388	16.777	9.9	9.956	19.913
7.0	8.451	16.902	10.0	10.000	20.000
7.1	8.513	17.025	100	20	40
7.2	8.573	17.147	1000	30	60
7.3	8.633	17.266	10000	40	80

*Or Current Ratio. To find the decibels corresponding to ratios above 10, break the ratio into two factors and add the decibels of each. For example: Voltage ratio = 400 = 4 x 100. Decibels = 12.041 + 40 = 52.041.

14 db, there is an output of 25.12 milliwatts for every milliwatt input.

Now let's use Table B. The first column is headed *Ratio*. This column can be used either for voltage ratios or power ratios.

Let's suppose we are considering a power ratio. We have an amplifier whose power output is 2 milliwatts and whose power input is 1 milliwatt, then:

$$\frac{P_2}{P_1} = \frac{2}{1} = 2$$

The power ratio is 2. In order to find the number of db that stands for this power ratio, you look in the *db (Power Ratio)* column for the number of db that corresponds to 2. The number of db is 3.010.

Let's suppose the ratio did not come out in even numbers. Suppose that you had a power input of 6 watts and a power output of 27 watts. The ratio would be as follows:

$$\frac{P_2}{P_1} = \frac{27}{6}$$

But the ratio in the first column of Table B is useful only when $P_1 = 1$. In order to make this so, we divide 27 by 6. The answer is 4.5. Then the ratio is:

$$\frac{P_2}{P_1} = \frac{4.5}{1}$$

We look in the second column of Table B, which lists the db equivalent for this power ratio and see that +6.532 db corresponds to this power ratio. In round numbers, we can say that this is 6.5 db.

If the ratio we are interested in is a voltage ratio, instead of using the second column of Table B to find the number of db, we use the third column. If we have an input of 10 volts and an output of 33 volts, the ratio would be as follows:

$$\frac{E_2}{E_1} = \frac{33}{10} = \frac{3.3}{1} = 3.3$$

We can see in the third column of Table B that the number of db is 10.370.

Values in between those listed can be found. For example, in order to find the

power equivalent of 33 db using Table A, break this quantity up so it reads 30 db + 3 db. Look up 30 db *Power ratio* = 1,000, then look up 3 db *Power ratio* = 1.995. Multiply the power ratios together. *The power equivalent of 33 db is 1,000 x 1.995 or 1,995.0.*

In order to find the db equivalent of the power ratio 12 from Table B, break this quantity up so it reads 6 x 2. Look up 6. *DB ratio* = 7.782 db, then look up 2. *DB ratio* = 3.010 db. Add the db ratios together. *The db equivalent of the power ratio 12 is 7.782 db + 3.010 db or 10.792 db.*

The voltage *ratios* in the tables refer to the so-called decibels-of-voltage units (dbvg) and are not normally convertible to power units. This means, for example, that an amplifier with a power gain of 100 does not necessarily have a voltage gain of 10, although these values both correspond to the decibel value 20 db in Table A. The voltage gain of an amplifier with a power gain of 100 is 10 only when an amplifier's input and output resistances are equal. In that case, both the voltage gain and the power gain are 20 db.

Let's see why this is so. The reference level for the *Voltage Ratio* column in Table A is 1 volt. The reference level for the *Power Ratio* column is 1 milliwatt. A formula for power is:

$$P = \frac{E^2}{R}$$

We know the values of P_1 (1 milliwatt) and E_1 (1 volt). Let's substitute into the formula, first converting 1 milliwatt into 0.001 watt. Then we have:

$$\begin{aligned} 0.001 &= \frac{1^2}{R} = \frac{1}{R} \\ R &= \frac{1}{0.001} \\ &= 1,000 \end{aligned}$$

In other words, 1,000 ohms is the resistance we need to satisfy this formula.

So, when we look up 20 db in Table A, we find that 20 db corresponds to a voltage ratio of 10 and a power ratio of 100. This means that 20 dbv is 10 volts and 20 dbm is 100 milliwatts.

If we shift our resistance level to another value, this relationship will not be the same. Let's suppose we use 500 ohms as a resistance level. Then although 20 dbv is still equal to 10 volts, because we are still using a reference level of 1 volt, when we calculate power by applying the 1 volt reference level across a 500 ohm resistance we have:

$$\begin{aligned} P &= \frac{E^2}{R_1} \\ &= \frac{1^2}{500} \\ &= 0.002 \text{ watts} \\ &= 2 \text{ milliwatts} \end{aligned}$$

Then, since 20 db means a ratio of 100 to 1, 20 db would stand for 200 milliwatts, instead of 100 milliwatts. When you know the resistance, it is possible to convert the statement of level in volts (20 dbv) to power.

26-2. MICROPHONES

The function of a microphone is to change sound waves into a varying electrical voltage. The exactness with which the electrical variations follow the sound waves is called fidelity.

Microphones are designed to work in definite frequency bands. If a microphone is to be used for recording purposes, broadcasting, or public address systems, it should have a steady output over range of frequencies from 40 to 15,000 cps. For communications work, such as amateur radio transmitters, police short-wave radios, shipboard

sets, military radio equipment, etc., the acceptable band is 75 to 4,500 cps.

In choosing a microphone you should also consider its *sensitivity* — the amount of output you get for a certain amount of sound input. The output is measured in decibels. The input is measured in *dynes per square centimeter* (dyne/cm²), a unit for measuring the strength of sound waves. A man speaking into a microphone with the microphone as close as possible to his lips exerts a sound pressure of approximately 100 dyne/cm². At a distance of 10 feet the pressure is about 10 dyne/cm². The weakest strength of sound that can be heard is 0.0002 dyne/cm².

Although the useful output of most microphones is voltage, both voltage decibels (dbv) and power decibels (dbm or db to some power reference other than one milliwatt) are employed in ratings of microphone sensitivity. Many kinds of decibel statements are used to rate microphone output. The kind used depends upon the microphone involved and the application for which it is intended. Some of these statements will be described as we come to the places in the course where they apply. Here are two examples:

1. A microphone's sensitivity might be expressed as *-80 dbv at one dyne/cm²*. From Table A, you can learn that *-80 dbv* means $\frac{1}{10,000}$ of one volt or 0.0001 volt. This 0.0001 volt is the microphone's output with one dyne/cm² of sound pressure applied. At higher sound pressures the output is greater.

2. A microphone's sensitivity might be expressed as *-50 dbm across 50 ohms at 10 dyne/cm²*. This means $\frac{1}{100,000}$ milliwatts (Table A) or 0.00001 milliwatts output at a sound pressure input of 10 dynes/cm². From this, the output in volts may be obtained from the formula:

$$P = \frac{E^2}{R}$$

Carbon Microphone. The main parts of the carbon microphone (Fig. 26-2) are a steel diaphragm, a button containing carbon gran-

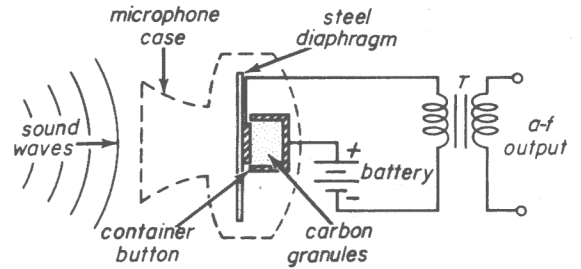


Fig. 26-2

ules, a battery, and a transformer. Sound waves that reach the microphone set up vibrations in the diaphragm. The vibrating diaphragm applies changing pressure to the button, thereby pressing the granules together each time the diaphragm is pushed in. As a result, the resistance of the button full of carbon granules varies. Notice that the button is in series with the battery and the primary winding of the transformer. The changing resistance of the button produces a corresponding change in the current flowing in this series circuit. As the varying current flows through the primary winding of the transformer, it induces an a-c voltage in the secondary winding. Thus, the sound waves are converted into voltage variations. The voltage variations correspond in frequency and intensity to the sound waves. The carbon microphone has a rated internal impedance of from 50 to 200 ohms.

(You'll learn more about the effects of the internal impedance of microphones when you study the Service Practices booklet on microphones and loudspeakers.)

Some carbon microphones have a double-button (Fig. 26-3). There is a container of

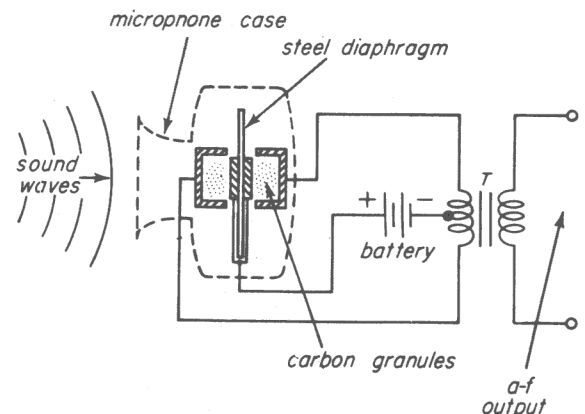


Fig. 26-3

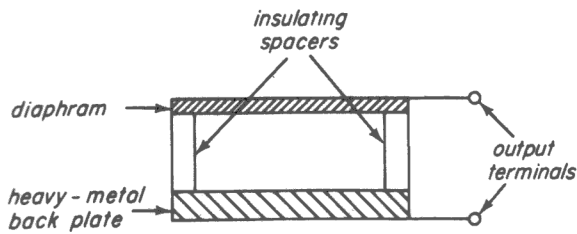


Fig. 26-4

carbon granules on each side of the diaphragm; and the battery is connected to a center-tap on the primary winding of the transformer. This is a push-pull circuit similar to that used in push-pull amplifiers. Like the amplifier circuit, the push-pull circuit of the double-button carbon microphone cancels distortion caused by even harmonics. Both kinds of carbon microphone are very sensitive (have high outputs), but they also have serious disadvantages. One of the disadvantages is a constant hiss caused by small variations in the contact resistance of the carbon granules. The hiss is most noticeable with soft sounds. Another disadvantage is a packing of the carbon granules that happens sometimes when the circuit is suddenly opened while current is flowing. Packing can be corrected by gently tapping the microphone to unpack the granules. While the granules are packed, the output of the microphone is greatly decreased. The carbon microphone is seldom used in commercial applications, but it is still used in connection with military equipment.

Condenser Microphone. In a *condenser* microphone (Fig. 26-4,5) the diaphragm is one plate of a capacitor. The other plate is rigid. Sound waves make the diaphragm vibrate, changing the gap between the two plates, so as to change the capacitance of the capacitor. This causes the capacitor to alternately charge and discharge in rhythm with the sound vibrations. The charge-discharge current flows to and from the capacitor, through the resistor, to and from the battery, causing a varying voltage to drop across the resistor. The voltage varies in rhythm with the sound. Thus, the original wave variations are changed into corresponding voltage variations. In this case, the variable electrical element in a condenser, whereas in the case of the carbon micro-

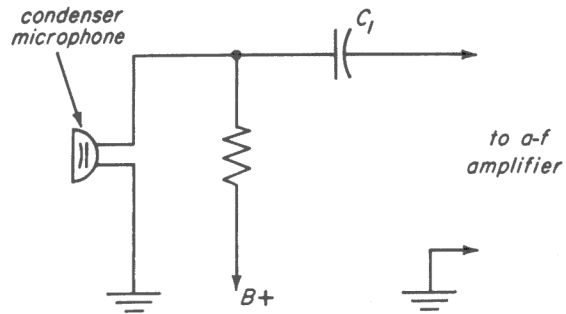


Fig. 26-5

phone, the variable electrical element is a resistor. As shown in Fig. 26-5, the output voltage is coupled to the first audio amplifier through C_1 .

The condenser microphone has high impedance, with good frequency response, but very low output. Because of the low output, only a very short lead is used between the condenser microphone and its amplifier in order to avoid lead loss. Two or three stages of amplification are built into the case of the microphone. The battery must supply about 200 volts. These factors combine to make the condenser microphone a very bulky and nonportable unit. Its use is confined to installations such as broadcast studios, where it is not necessary to carry the microphone from place to place.

Dynamic Microphone. The *dynamic*, or moving-coil microphone operates on the principle of electromagnetic induction (Fig. 26-6). A coil of fine wire is fastened to a diaphragm. The coil fits between the poles

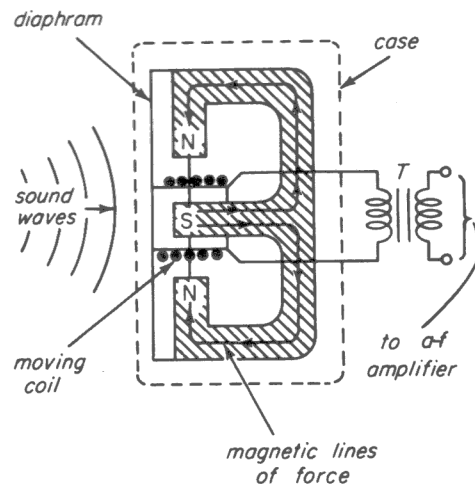


Fig. 26-6

of a powerful permanent magnet. As with the two other microphones we have discussed, the diaphragm vibrates when sound waves reach it. The vibrating diaphragm moves the coil back and forth. The coil moves between the poles of the permanent magnet. Clearance between the coil and the magnet is made very small so that the coil may cut as many lines of force as possible. When the magnetic lines of force are cut by the coil, a voltage is induced. The voltage that is induced in the coil corresponds in frequency and intensity to the sound wave vibrations set up in the diaphragm. The induced voltage is the output of the microphone; it is coupled to a step-up transformer, which in turn feeds an amplifier.

The impedance of a dynamic microphone is low, and therefore, it is possible to use long cables without excessive hum pickup. The cables should be shielded; otherwise stray pickups will combine with the output of the microphone even though the impedance is low. The sensitivity of the dynamic microphone is very good, and although it is not as good as that of the carbon microphone, other features make it a better all-around instrument. It is small in size and light in weight; therefore, it is portable. It has long life, and does not require much maintenance. It does not need a battery supply. The frequency response is very good, and the microphone is considered to be excellent for high-quality sound reproduction. The chief disadvantage of the dynamic microphone is its directional response. It will pick up sounds in only one direction when the frequency is above 1,000 cps. However, this is remedied by careful design. The diaphragm is mounted so that it faces the ceiling. This way, sounds from any horizontal direction make the diaphragm vibrate with equal force.

Velocity Microphone. The *velocity* or ribbon microphone (Fig. 26-7) is a variation of the dynamic microphone. The main parts are a metallic ribbon and a strong, permanent magnet. The ribbon is a thin, lightweight metal strip, flexible because it is corrugated. It hangs between the poles of the magnet with very little clearance between the edges of the ribbon and the magnet. Clearance is suffi-

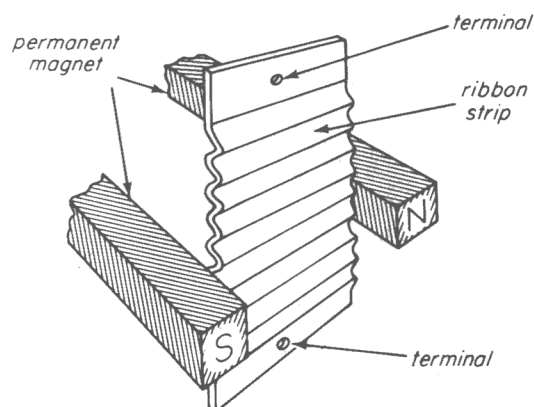


Fig. 26-7

cient to allow the ribbon to move back and forth without touching the sides of the magnet. Sound waves reaching the microphone set up vibrations in the ribbon. As the ribbon vibrates, it cuts the lines of force of the magnet, and a voltage is induced. The voltage induced in the ribbon corresponds to the sound waves in frequency and strength.

The terminals of the ribbon are connected to the primary winding of a transformer through which the electrical variations are transferred to the output circuit. The name of this microphone reminds us that the velocity (speed), rather than the distance of movement of the ribbon, corresponds to the strength of the sound waves.

The ribbon is very delicate, and so the microphone is constructed to protect the ribbon from mechanical injury or sudden gusts of wind. The velocity microphone is almost as rugged as the dynamic type, and it is as good as the dynamic mike in portability, freedom from maintenance problems, and good frequency response. An important difference is that, while the dynamic microphone can be designed to pick up sounds from all angles, the velocity microphone picks up only sounds that come from directly in front or in back of it. Output impedance is low so it is possible to use long cables, if they are well shielded. Velocity microphones are used in broadcast stations and public-address systems.

Crystal Microphone. The *crystal* microphone depends upon the piezoelectric properties of crystals. Certain crystals produce

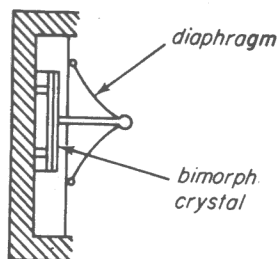


Fig. 26-8

a voltage when they are subjected to outside pressures. Rochelle salt crystals have greater voltage output than other crystals, and for this reason, it is most used in crystal microphones. In order to obtain greater sensitivity, two thin slabs of crystal are clamped together to form a bimorph cell. In one type of crystal microphone, a lightweight diaphragm is mechanically coupled to the bimorph cell (Fig. 26-8). The diaphragm is made to vibrate by sound waves, and the vibrations are transmitted to the bimorph cell in a way to twist the crystal. Twisting produces a voltage at the terminals of the bimorph cell, and the voltage is fed to an amplifier. The voltage output of this type of crystal microphone is high, but the frequency response is limited because of the stiffness of the diaphragm.

Another type of crystal microphone does not have a diaphragm (Fig. 26-9). It is known as a sound-cell type microphone. Sound waves strike the crystal plates directly and cause them to vibrate. A number of bimorph cells are employed because the sensitivity of a single cell without a diaphragm is insufficient. The bimorph cells are arranged so that the voltages developed by vibration cancel each other when the unit is subjected to mechanical shock, but the voltages aid each other when sound waves cause the crystals to vibrate.

A crystal microphone has a high impedance. It does not require an outside voltage or current to operate. The cable between microphone and amplifier may be up to twenty-five feet in length. For minimum cable loss, it should have a low value of shunt capacitance. This microphone is rugged, lightweight, and does not produce

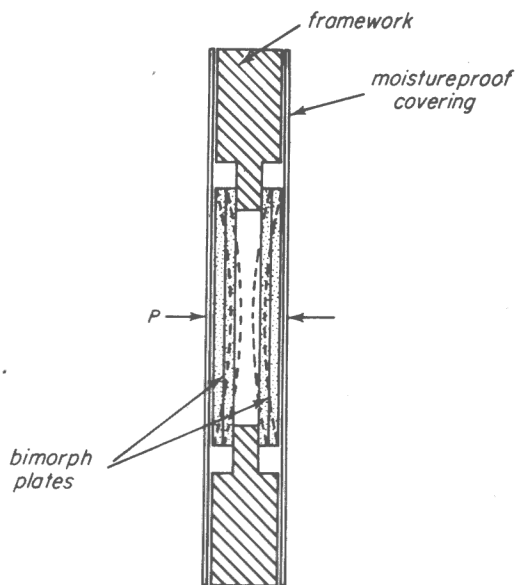


Fig. 26-9

any noise of its own. Unlike the dynamic or the velocity microphones, the crystal type can pick up sound from all directions

Other Microphones. Some miscellaneous classifications of microphones are the directional, contact, and lapel microphone. One directional microphone combines the outputs of a dynamic microphone and a velocity microphone. Both are mounted in the same case. A switch may be operated to select one of three different responses: unidirectional, or pickup from one direction only; bidirectional, or pickup from two different directions; and non-directional, which allows sound waves to be received from all directions.

The contact microphone receives its vibrations from direct contact with the object that produces the sound. It may be placed against a musical instrument, a mechanical object, or a part of the human body. (Many of us are familiar with the throat microphone and the lip microphone, which are contact microphones used in the military service.) The chief advantage of the contact microphone is its ability to pick up the vibrations from the sound source itself, and at the same time not pick up outside noises.

The lapel microphone is a small, lightweight microphone worn on the lapel of a

person who is broadcasting. It is very convenient in cases that require an announcer to move around and have the free use of his hands. Reproduction of speech and music is fair with a lapel microphone but it is not used when high-quality reproduction is desired.

26-3. EARPHONES

In our discussion of microphones, we considered the process involved in changing sound waves to electrical variations. In this and the next section, the reverse operation will be discussed. The function of earphones and loudspeakers is to convert electrical variations present in the output stage of an amplifier into sound waves corresponding as closely as possible to sounds that were spoken or played into a microphone.

In the early days of radio, only earphones were available to hear the output of radio sets. Today earphones are used when it is desired to listen to a radio set late at night so that the neighbors will not be disturbed. Earphones are used in broadcasting studios, in ground and air communications, and by amateur radio operators.

Figure 26-10 shows a cross section view of a *magnetic* earphone. It consists of a diaphragm, two pole pieces connected by a curved permanent magnet to form a horseshoe magnet, and two coils connected in series. The diaphragm is made of very thin soft iron. It is flexible. It is mounted above the two permanent magnets, very close to the pole pieces. Each coil is wound around one of the two permanent magnet pole

pieces. When the coils do not carry current, the diaphragm is bent slightly in the direction of the pole pieces by magnetic attraction. This is illustrated as position 1 of Fig. 26-10. During one half of a cycle of audio current in the coils, the magnetic field of the permanent magnet is aided by magnetic force resulting from the flow of audio current through the coil, and so the diaphragm is attracted to position 2 of Fig. 26-10. The audio current reverses in the other half of the cycle, and then the magnetic field of the coils opposes that of the permanent magnet. This causes the force of attraction to decrease to the extent that the diaphragm springs back in the opposite direction to position 3. The back and forth motion of the diaphragm, which corresponds to the variations of an output audio signal, causes the air to vibrate, thus producing sound waves.

If unmagnetized iron pole pieces were used in place of the permanent magnet, a double-pitched sound output (second harmonic distortion) would result. A half cycle of the audio signal would magnetize the iron pole piece in the polarity shown in Fig. 26-10. The next half cycle would reverse the north and south poles. Since the diaphragm is attracted by the magnet in either polarity, two vibrations of the diaphragm would result from a single cycle of audio signal. The permanent magnet prevents this by maintaining a single magnetic polarity (that shown). The audio signal varies the strength of the permanent magnet's pull upon the diaphragm without changing the magnetic polarity of the pole pieces.

A magnetic earphone is similar in operation to a telephone receiver. Another type of earphone uses the principle of piezoelectricity. This property of certain crystals is employed in one kind of phonograph pickup and one kind of microphone. A voltage is produced when certain crystals are subjected to sound pressures. The effect is reversible. That is, when a voltage appears across certain crystals, the crystals change shape. The crystal headset contains a bimorph crystal of Rochelle salt instead of the permanent magnets and coils. The output of an

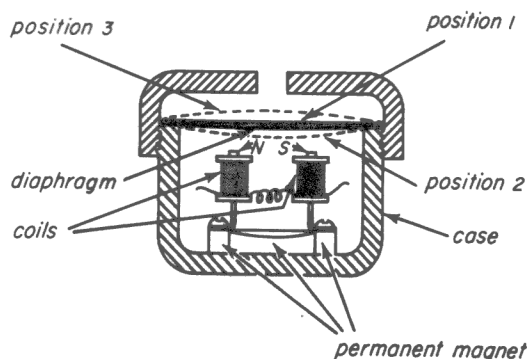


Fig. 26-10

audio amplifier is connected to the terminals of the bimorph crystal. When there is no output, the diaphragm is in its normal position. During the first half of an audio-voltage cycle, the crystal changes in shape and causes the diaphragm to move in one direction. The second half of the audio cycle twists the crystal in the opposite way, and this makes the diaphragm move in the opposite direction. The vibrations of the diaphragm set the surrounding air in motion, thus producing sound waves.

26-4. LOUSPEAKERS

The use of earphones limits listening to the persons using the phones. If it is desired to reproduce sounds for the benefit of many people, a loudspeaker is needed. Few components of a radio or television receiver lend themselves to differences of personal taste concerning quality as much as loudspeakers do. What may sound like a pleasing loudspeaker response to one person is disliked by another. A change from one loudspeaker system to another can make a big difference in the performance of a radio. A system can consist of only one loudspeaker, or it may contain two or three. The system can be arranged to bring out the low frequencies more sharply than the highs, or vice versa. By means of proper selection of loudspeakers, it is possible to obtain practically uniform response over the entire range of audio frequencies. At the present time, there is a tendency for the home music listener to desire better quality than in the past, and, therefore, it is necessary for servicemen to be familiar with the several varieties of loudspeaker that are available.

The average person can easily realize that deep bass notes, which are of a low frequency, come from large speakers, because he has heard such notes from large musical instruments such as bass fiddles and tubas. Likewise, he can know that the higher notes are best produced in smaller loudspeakers, for he has heard these notes coming from smaller musical instruments like the piccolo and the flute. Thus, an ideal way to combine speakers is to use a small speaker for the

high frequencies and a large speaker for the lows, and to design them so that each one will reject frequencies that the other accepts. This is not always practical.

The merit of one type of loudspeaker over another should be considered in the light of the space available for installation. We may limit ourselves to an 8-inch loudspeaker in order to build it into a bookshelf. An 8-inch loudspeaker represents a good compromise choice of size that insures adequate reproduction of both high and low frequencies. A 15-inch speaker is better for the low frequencies, but not for the highs. Because of these factors, we find speakers classified as *woofers*, *tweeters*, and middle-range loudspeakers or *squawkers*. All of these will be discussed in this section.

Loudspeakers radiate (put forth) sound in two basic ways. There are *direct radiators*, and there are *compression-driver, horn-loaded radiators*. A direct radiator is a speaker whose diaphragm or cone faces into the room, with nothing between it and the listener except a grille cloth and the air. The rear of this speaker faces into a box-like cavity. A compression-type driver unit is a loudspeaker in which the rear of the unit is tightly sealed off in a small chamber, and the front of the diaphragm plays into a horn before the sound reaches the listener.

The earliest loudspeaker operated as a large version of the magnetic earphone. (See Fig. 26-11) This kind of loudspeaker operation is called *electromagnetic*. The main components are a permanent magnet, with coils of wire wound around the pole pieces, an armature, and a cone. The coils are in series, and are connected to the out-

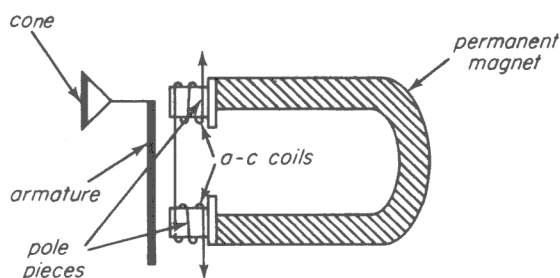


Fig. 26-11

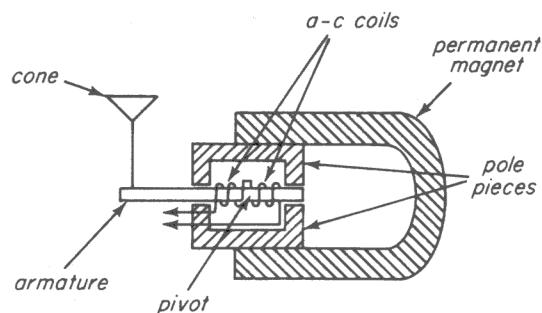


Fig. 26-12

put of the radio receiver. When no current is flowing through the coils, the permanent magnet attracts the armature only slightly. Audio-frequency current flowing through the coils will strengthen the magnetic field during one half-cycle, and weaken it on the other half-cycle. The armature will move back and forth in accordance with the audio-current variations and cause similar vibrations in the cone, thereby setting the air in motion and producing sound waves.

Figure 26-12 illustrates another kind of electromagnetic loudspeaker called a balanced armature speaker. The armature is balanced between the pole pieces of a horseshoe permanent magnet.

Audio currents flowing through the coils cause the armature to be attracted first to one pole piece and then to another. As the armature moves, it drives the cone, and sound waves are produced.

Electromagnetic speakers have a high impedance that is approximately equal to the plate impedance of output tubes. For this reason, such speakers can be used without an output transformer. The loudspeaker coils are connected directly to the plate of an audio-frequency power amplifier. This has been an important factor in the design of small radio receivers where the bulk and cost of an output transformer can present problems. The chief disadvantage of this type of speaker is its low output. Electromagnetic speakers are practically obsolete.

Most modern loudspeakers are of the *dynamic* or moving-coil type. They may either be of the electrodynamic, or of the permanent magnet (PM) kind. Figure 26-13

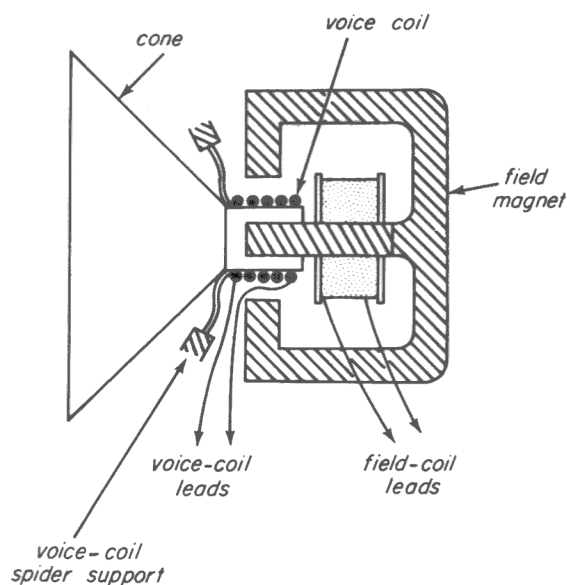


Fig. 26-13

shows an electrodynamic loudspeaker. The main parts are an electromagnet, consisting of a field coil and pole piece, a voice coil, and a cone. The voice coil is wound on a hollow cylinder of cardboard that is fitted loosely over the center pole of the field magnet. One end of the voice-coil cardboard is attached to the cone. The voice coil on its cardboard mount is free to move back and forth over the center pole of the magnet, but the so-called *spider* support prevents the coil from moving in any other direction. The field coil is usually connected into the filter circuit of a radio's rectifier power supply, and is therefore energized by a d-c current that is somewhat filtered of pulsations. The field coil is often used as an extra filter choke in series with the main filter choke coil. When current flows in the field coil, a strong magnetic field is produced between the pole pieces of the electromagnet. Audio currents in the voice coil set up magnetic fields that aid and oppose the magnetic field set up by the field coil. Attraction and repulsion between the two magnetic fields causes the voice coil to move back and forth, and so the cone is made to vibrate at an audio rate, setting up waves of sound.

One disadvantage of the electrodynamic loudspeaker is that a certain amount of hum is picked up by the voice coil from the field coil, so hum is radiated with the wanted

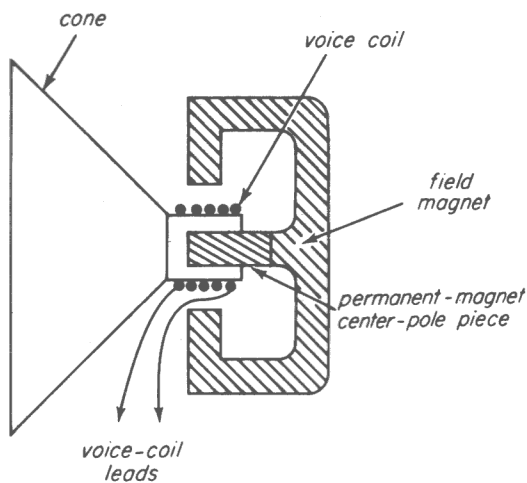


Fig. 26-14

sound. This hum is produced by an a-c ripple component that may be present in the direct current that energizes the field coil. In order to cancel this hum, most speakers have a special coil known as a *hum-bucking* coil that is wound around the field to pick up some hum voltage. The hum-bucking coil is connected in series-opposition to the voice coil so that the hum voltage across the hum-bucking coil eliminates the hum component of the voice coil.

The use of a *PM speaker* is the most effective way of eliminating hum. The majority of loudspeakers in present-day radio and television receivers are of the PM (permanent magnet) type (Fig. 26-14). The field magnet is a permanent magnet instead of an electromagnet. Otherwise, the operation of the PM speaker is the same as that of the electrodynamic speaker. PM speakers are practical today because experiments with magnetic materials have resulted in magnets of high flux density and small size. One very popular material in common use is alnico, an alloy of aluminum, nickel, and cobalt, with some iron. The commercial name for this material is Alnico V.

We have been discussing direct radiator loudspeakers. It may be surprising, but the efficiency of this class of speaker averages between 1 and 5 percent. The reason for this low efficiency can be explained as follows. The most efficient transfer of power from a source to a load in an electrical system takes place when the two

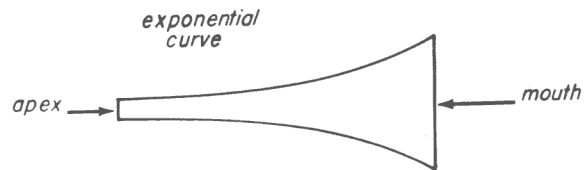


Fig. 26-15

impedances are about equal. The same principle holds for mechanical and other power system, for these have impedances too. In direct radiator speakers, the moving diaphragm or cone has a large impedance for sound waves, but the surrounding air to which the moving cone's power must be transferred has a low impedance. This difference in impedances accounts for the low efficiency with which the direct radiator speaker sets up sound waves in air.

A horn-loaded radiator ranges in efficiency from 25 to 50 percent. The horn is the mechanical equivalent of an electrical transformer; it provides a means of matching the impedances of the cone and that of the surrounding air. A diagram of a straight, exponential horn is illustrated in Fig. 26-15. The word exponential refers to the fact that the curved portion of the horn follows a definite mathematical formula, which need not be given in this discussion. The diaphragm of a PM speaker is located at the apex, or narrowest part of the horn. At the apex, the resistance of the air is high, matching that of the diaphragm. The entire force of the diaphragm is being used to move a column of air confined in a very small space, and therefore resistance must be high. Towards the mouth of the horn, its diameter is larger; it confines the air in a larger space. Here, the air offers less resistance to being moved (has lower impedance). Since enlargement of the diameter of the horn is gradual, the impedance of the air within the horn decreases gradually as the sound wave travels toward the horn's mouth.

Straight horns are very practical for the high frequencies, but in order to operate with success at about 50 cps, the length of the horn has to be about 16 feet, and the mouth diameter about 14 feet. It is possible to fold the horn so that it occupies less space, and to use the walls of a corner of a

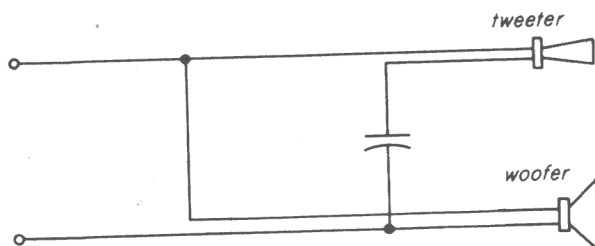


Fig. 26-16

room as an extension of it. With an arrangement of this kind, the results are not as good as those obtained with a straight horn. However, it is practical, and there are many folded horns on the market that give excellent results.

Loudspeakers can be combined into two- or three-speaker systems. The use of more than one speaker can improve the reproduction of low and high frequencies. A speaker that is 12 or 15 inches in diameter improves the low-frequency response. This is commonly known as a woofer. The woofer is usually a direct radiator, or cone-type speaker. The high-frequency speaker is called a tweeter, and it is often a horn-type speaker. The woofer and tweeter are combined in a single cabinet.

To extend frequency response, it is not sufficient to connect two speakers in parallel or in series and let it go at that. The best results are obtained when the woofer accepts one band of frequencies in the low range, and the tweeter reproduces the balance of the audio range. To accomplish this, we use a *crossover* network. This is a filter system that accepts the whole range of audio frequencies at its input, then separates the

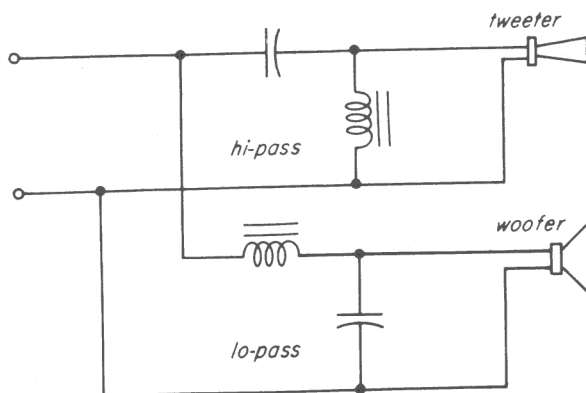


Fig. 26-17

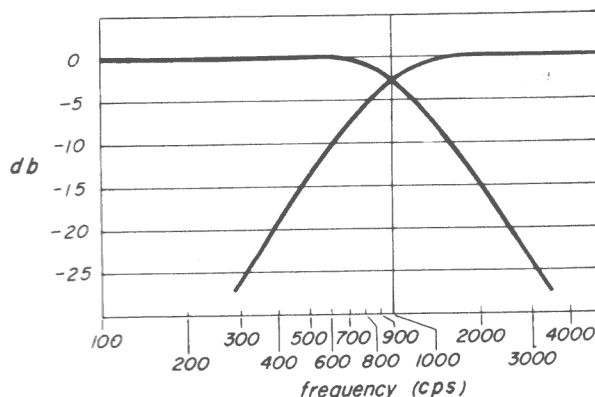


Fig. 26-18

lows from the highs, and sends the lows into the woofer, and only the highs into the tweeter. The crossover frequency is the frequency at which the separation from one band to another takes place. This frequency must be high enough so that the lowest frequency to get into the tweeter is not low enough to cause damage. A simple crossover network is illustrated in Fig. 26-16. Notice that the woofer receives all of the frequencies. The capacitor in series with one lead to the tweeter is small enough to prevent low frequencies from reaching the tweeter.

A better network is illustrated in Fig. 26-17. The woofer is fed through a low-pass filter, the pass response of which drops off sharply above the crossover frequency. The tweeter is fed through a high-pass filter, the pass and response of which falls off very fast below the crossover frequency. As an example, Fig. 26-18 shows how the band is divided between the two speakers if the crossover frequency is 1,000 cps. Notice that the woofer shows a uniform response from 40 to about 600 cps. Then the response starts to drop. At 1,000 cps, the drop is about -3 db. The tweeter has a uniform response from 15,000 back to about 1,700 cps. At this point it drops, so that at 1,000 cps, the response is -3 db. A drop of 3 db can scarcely be detected by the human ear. The tweeter reproduces all frequencies above 1,000 cps, and the woofer reproduces the band from 40 to 1,000 cps.

A three-way system has a woofer, a tweeter, and a middle-range speaker called

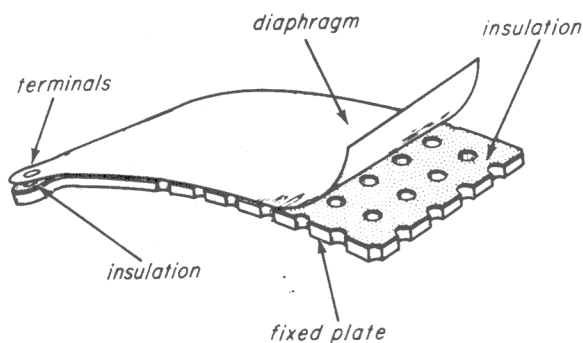


Fig. 26-19

a squawker. Better performance is to be expected from a three-way system than from a two-way system. Each of the three speakers operates in a narrower band than the two-way system, and therefore, works with greater efficiency. A three-way crossover network is necessary. This is designed to have two crossover frequencies — for example, 600 and 4,000 cps. In a system like this, the woofer will reproduce from 40 to 600 cps, the middle-range speaker 600 to 4,000 cps, and the tweeter 4,000 to 15,000 cps.

Recently an unusual kind of loudspeaker has been employed as a tweeter in some radio sets. This is the condenser loudspeaker or electrostatic loudspeaker (Fig. 26-19). The moving diaphragm is one plate of a capacitor. The other plate is a stiff-perforated sheet of metal. Perforations (holes) prevent the diaphragm from sticking to the fixed plate by air suction. The two plates are insulated from each other. The diaphragm moves due to an electrostatic attraction and repulsion that is exerted between the plates. The varying electrostatic field that causes the attraction and repulsion is created when a voltage varying at an audio rate is applied to one plate. (The other plate is grounded.) A polarizing d-c voltage must also be applied to prevent second harmonic distortion (the double pitch effect described for magnetic earphones). A typical value of polarizing voltage is 400 vdc.

No output transformer is needed with condenser loudspeakers. They work by means of voltage and so are driven by a voltage amplifier rather than a power amplifier. Because the distance of movement of

the diaphragm is very short, an impractically large diaphragm would be required to reproduce low notes loudly. Therefore, the speaker is used only as a tweeter.

There is a loudspeaker that is a two-way frequency range system in itself. It is called the coaxial speaker (Fig. 26-20). In this type, the high-frequency unit is mounted within the low-frequency speaker's voice coil. The speaker is considered a single unit. A triaxial speaker is a combination of three speakers mounted one within the other. Coaxial and triaxial speakers need crossover networks just as do two- and three-speaker systems that use completely separate units.

The best loudspeaker will sound like a small table-model radio receiver if it is used without a baffle. A baffle is simply a board or an enclosure for mounting the speaker. There is an additional purpose for using a baffle. The baffle reduces low frequency cancellation caused by sound waves that travel from the back of the speaker and then reach the ear. These are called back waves. If the speaker is mounted on a board, called

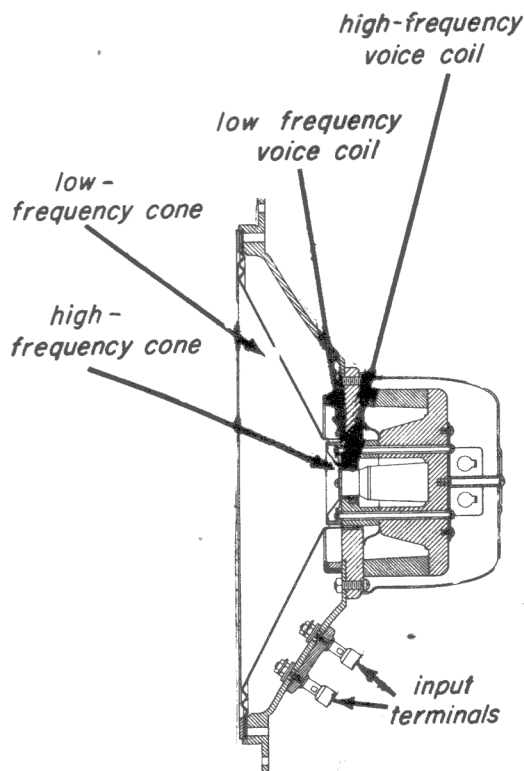


Fig. 26-20

a flat baffle, the back waves have a greater distance to travel before they reach the ear, and they will not cancel the front waves. A closed box produces even better sound than a flat baffle, because the back waves have no way at all of getting out to interfere with the front waves. The box should have only one hole, the speaker mounting hole, exactly of the same diameter as the speaker. The speaker is mounted on the inside of the box before the box is sealed off. Such a baffle should be somewhere between 7 and 15 cubic feet in volume. It should be solidly built, and preferably lined with an absorbent material, such as felt. The sealed box is called an infinite baffle, because none of the back waves can be radiated into the outside air; the back waves are infinitely attenuated.

A special type of baffle is illustrated in Fig. 26-21. It is called a bass-reflex enclosure. It looks like an infinite baffle, except that it has additional openings referred to as ports. All loudspeakers have a resonant peak at a single low frequency. The response is so great at this frequency that it gives the effect of a single bass note. The

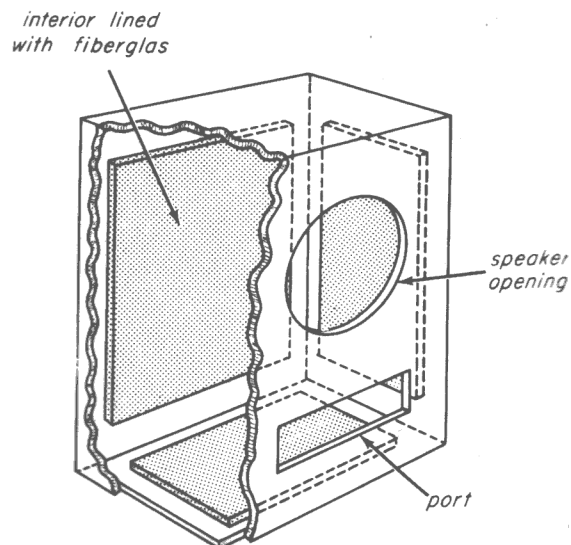


Fig. 26-21

purpose of the port in the bass-reflex enclosure is to allow the back waves to be radiated so that they oppose and reduce the loudness of the front waves at the resonant frequency of the speaker. In order to do this, a bass-reflex enclosure must be designed with great care. The size of the box and the size of the port must be such that the frequency of resonance of the box and port is the same as the resonant frequency of the loudspeaker.